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DEVELOPMENT OF AIFTDS-4000, A FLIGHT-QUALIFIED, FLEXIBLE,
HIGH-SPEED DATA ACQUISITION SYSTEM

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SUMMARY

The NASA Flight Research Center has developed a prototype data acquisition system which integrates an airborne computer with a high-speed pulse code modulation system. The design of the airborne integrated flight test data system (AIFTDS) is the result of experience with airborne pulse code modulation data systems. The AIFTDS-4000 has proved the premise on which it was designed: that the needs and requirements of data acquisition system users can be integrated to produce a highly flexible system that will be more useful than existing systems.

INTRODUCTION

The NASA Flight Research Center first started using pulse code modulation (PCM) as a research data acquisition system in 1964. The PCM concept was successful from the beginning. Eventually, every major flight project at the Flight Research Center was instrumented with a PCM data system. Today all the flight projects use PCM systems.

During the years following 1964, much experience was gained from the variety of research aircraft on which PCM systems were used. As the PCM system gained favor among data acquisition system users, increasing demands were placed upon it. It rapidly became apparent that greater capabilities and flexibility were necessary if future needs were to be met.

To obtain a thorough understanding of these future needs, all the improvements desired by PCM system users were listed, and the list was condensed into six major objectives:

- To sample, measure, and digitize flight research data on a variety of research aircraft.
- To direct channel sampling sequences from prestored formats.

- To reduce research aircraft turnaround time by incorporating system self-checkout (without use of aircraft's power).
- To perform airborne real-time computations and monitoring on selected samples and merge the result with the bit stream.
- To provide the flight crew or pilot with a display of selected measurements or computed results.
- To provide system flexibility in channel capacity, word rate, word length, and time correlation.

These major objectives were resolved into specific design goals for an airborne integrated flight test data system. These design goals are discussed in detail in this paper.

DESCRIPTION OF THE AIFTDS

The AIFTDS-4000 is made up of three basic chassis: one processor unit and one memory unit, which are collectively referred to as the airborne computing system (ACS) (fig. 1), and the remote multiplexer/demultiplexer unit (RMDU) (fig. 2). A simplified block diagram (fig. 3) illustrates the relationship of the units and shows the system's capacity of up to 16 RMDU's. The existing RF transmitter and tape recorder are included to present a complete system concept. The block diagram also shows the clock, address, and data wires required for each RMDU/ACS interface. The AIFTDS is described in more detail in reference 1.

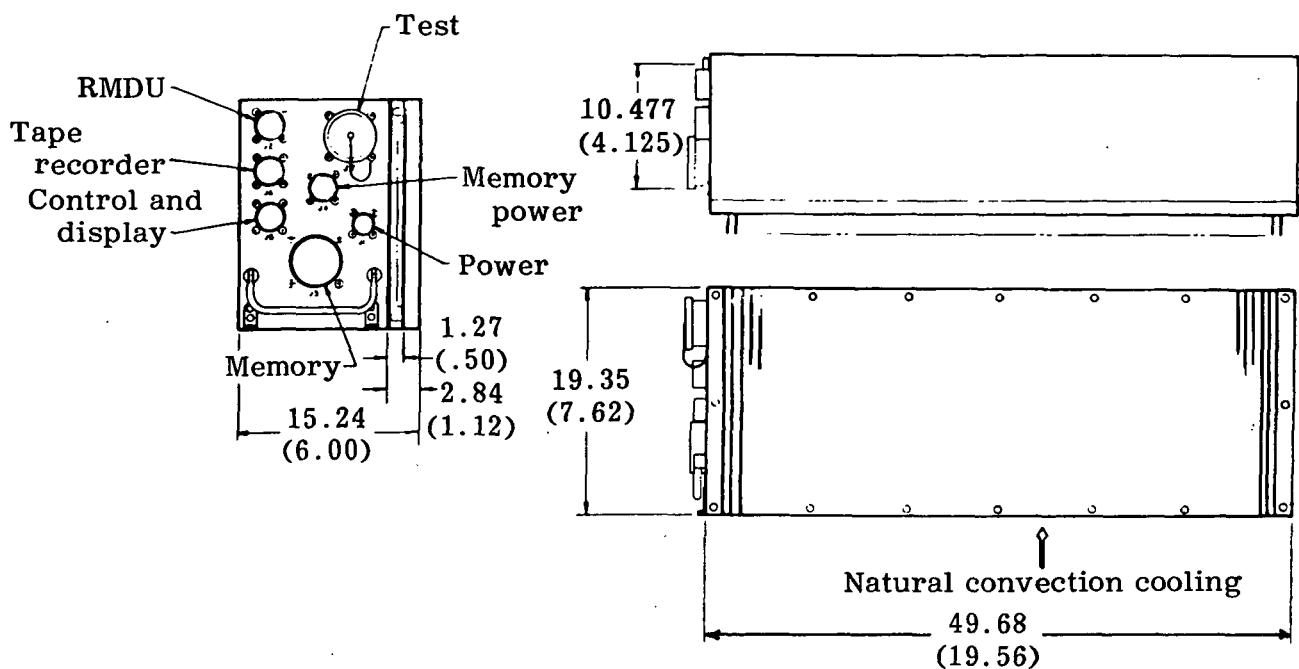
From a technological point of view, the AIFTDS is comprised of existing hardware and circuit designs. Some of the circuits and hardware have been redesigned and improved, but for the most part the AIFTDS consists of carefully selected hardware representing existing technology. What makes AIFTDS unique is the manner in which these bits and pieces have been integrated and the almost complete elimination of the "black box" modularity concept.

In most data acquisition systems, flexibility has traditionally been achieved by using black boxes or modules, that is, a separate module (or chassis) for sensor excitation, a separate signal conditioning chassis for each type of sensor, time code generators, and so on. The AIFTDS uses printed circuit card modularity and is thus able to integrate most of these modules into the RMDU and the airborne computing system. The effect of this concept can be recognized in nearly all the data acquisition system improvements which have resulted in increased AIFTDS flexibility.

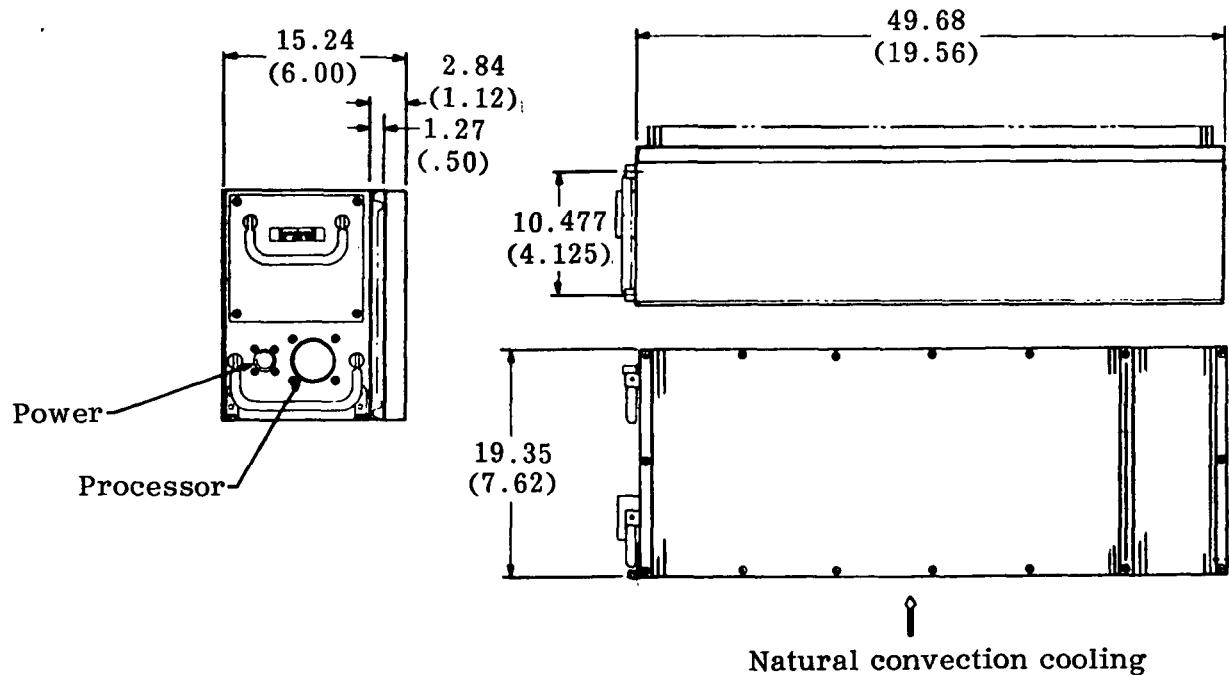
AIFTDS DESIGN GOALS

The AIFTDS design goals were, briefly, to:

Reduce data acquisition system weight, size, and costs.



(a) Processor unit.



(b) Memory unit.

Figure 1. AIFTDS airborne computing system (ACS). Dimensions in centimeters (inches).

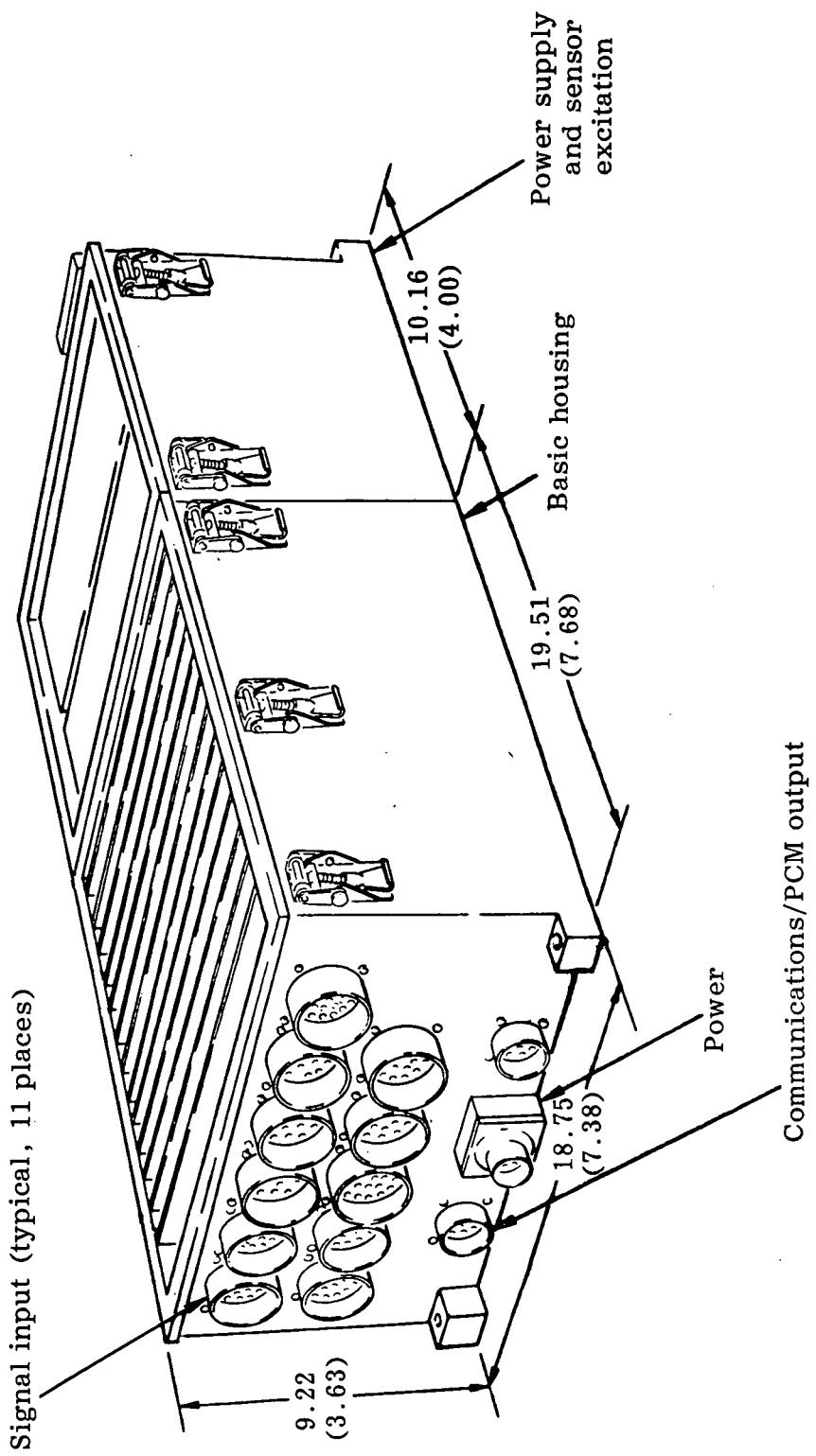


Figure 2. AIFTDS remote multiplexer/demultiplexer unit (RMDU). All dimensions in centimeters (inches).

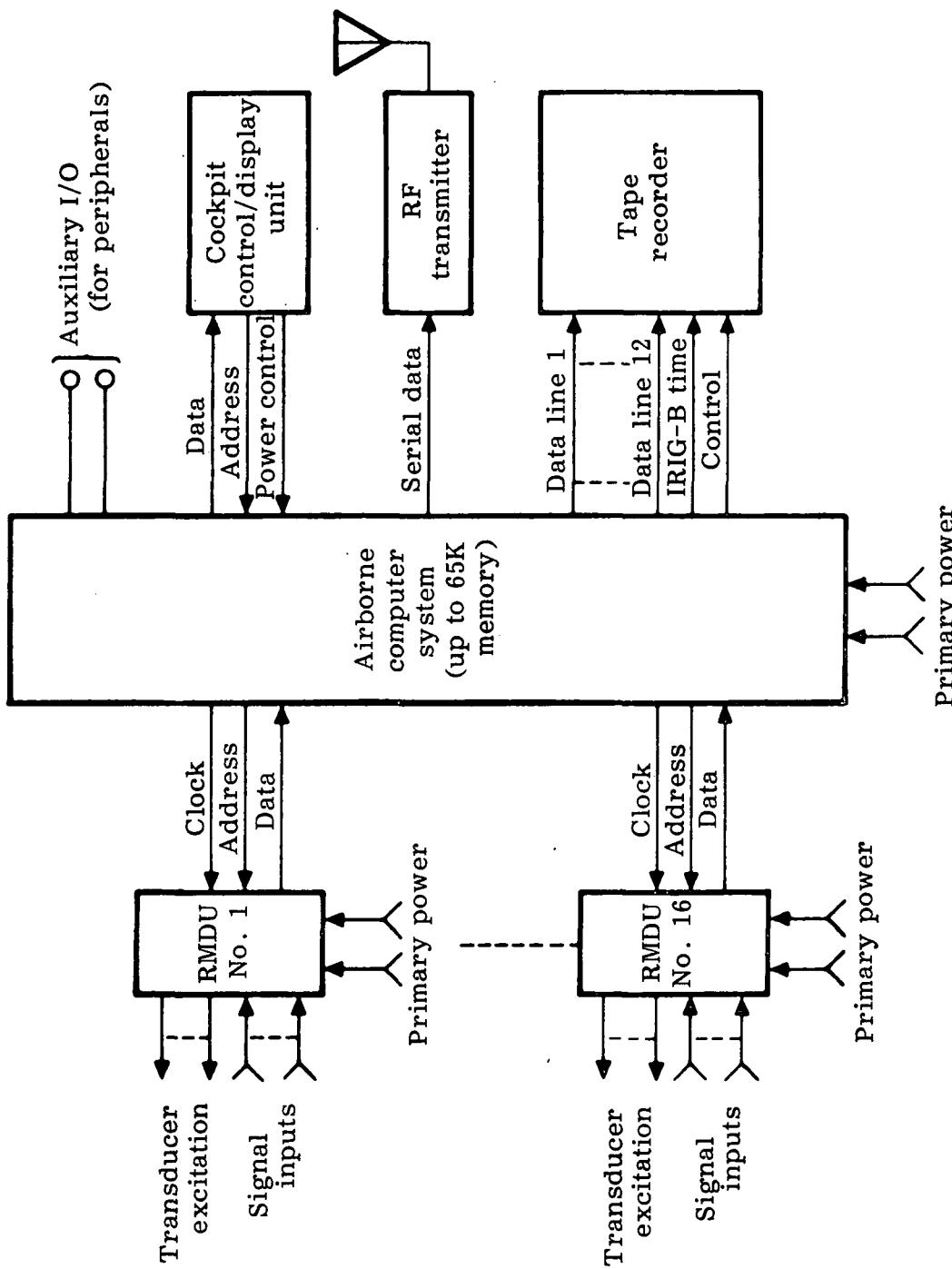


Figure 3. Simplified block diagram of AIFTDS.

Reduce aircraft instrumentation installation time.

Provide supplemental software to assist in maintenance.

Reduce data acquisition system noise susceptibility.

Provide flexibility for large and small aircraft.

Provide simultaneous sampling and adaptive gain.

Provide data management flexibility.

Provide for future growth.

Each of these goals, which ultimately led to the AIFTDS hardware, is discussed to point out how the needs and requirements of data acquisition system users were integrated to produce a highly flexible airborne data acquisition system that is more useful than existing systems.

Reduce Data Acquisition System Weight, Size, and Costs

Weight and size.— Reducing the weight and size of a typical data acquisition system was approached with two goals in mind: (1) to reduce data acquisition system chassis count and (2) to reduce data acquisition wiring. The integration of each data acquisition system module into the ACS or the RMDU essentially accomplished both of these goals. The chassis weight and mounting provisions of each module and the interconnecting wiring and connectors between modules were eliminated; and ACS cabling to each RMDU was reduced to three twisted shielded pairs. These changes in conjunction with remote installation of the RMDU resulted in the projected savings in weight shown in figure 4(a). If such items as disconnect panels, bulkhead connectors, and cable clamps had been included, the savings in weight would have been even greater; however, this tabulation was derived from hardware listings only.

The RMDU was designed to incorporate all signal conditioning within its chassis as well as to provide all sensor excitation. To accomplish this the unit was designed to accept a wide variety of signal conditioning/multiplexer cards.

The size and shape of the RMDU (fig. 2) permit the use of long printed circuit card connectors. The greater number of connector pins available facilitated the design of a variety of signal conditioning cards, each of which may be plugged into the same card slot. Once a card is installed and the software prepared, any card of the same type may be installed in that card slot without modifying the controlling software. Furthermore, the calibration is not affected.

This approach to flexibility not only saves weight and space while providing standardization but also does not "tie up" the signal conditioning in a hangared aircraft when it could be used on a flying project, and allows the "empty" RMDU housing to be permanently installed in an aircraft so that the proper fit checks can be

confirmed, cabling properly routed, and sensors permanently hardwired to each RMDU. The signal conditioning cards can be installed later when the aircraft is ready for system functional tests. In addition, if the system user has transducers with self-contained signal conditioning, the RMDU is still compatible. In this instance, each appropriate card slot is filled with an analog multiplexer card.

Costs.— Any attempt to provide a theoretical cost analysis is at best somewhat subjective. Yet certain observations about the AIFTDS can be made. For example, as shown in figure 4(b), the difference in system costs is primarily a result of the reduction of wiring (fig. 4(a)), associated connectors, and the manhours required for installation of these cables. For larger systems, the AIFTDS hardware shows an additional savings, since the AIFTDS utilizes RMDU's to minimize the length of transducer and signal conditioning wiring.

Reduce Aircraft Instrumentation Installation Time

Aircraft are generally designed, built, and delivered operationally prepared for flight but uninstrumented. Any slip in the schedule is usually passed on to the last phase: instrumentation. The AIFTDS is ready for installation as soon as the aircraft "keel" is laid. This is practical, since the wiring between each RMDU and the ACS consists of a fixed number of wires. The RMDU housing without internal cards is remotely installed, and all sensor wires can be permanently routed and hardwired to it. The system configuration can be determined later by choosing the proper signal conditioning cards for each sensor.

Every research vehicle has some sensors that must be installed concurrently with airframe construction. During this installation it is usually difficult, if not impossible, to apply power to these sensors and check them out through the data acquisition system. The AIFTDS address generator was designed to alleviate this problem both on the aircraft during construction and on the research vehicle in flight status. Briefly, an RMDU with the proper card(s) installed, the sensors to be tested, and the address generator comprise a test configuration. In this configuration the address generator is plugged into line power (60 Hz), the RMDU is connected to the address generator, and the sensors are wired to the RMDU. This system provides sensor excitation, signal conditioning, and channel select readout. All that remains to be done is to exercise the sensor(s). Assuming there will be no changes in sensor characteristics, calibrations may also be made at this time, since using the address generator instead of the ACS will not affect the calibration.

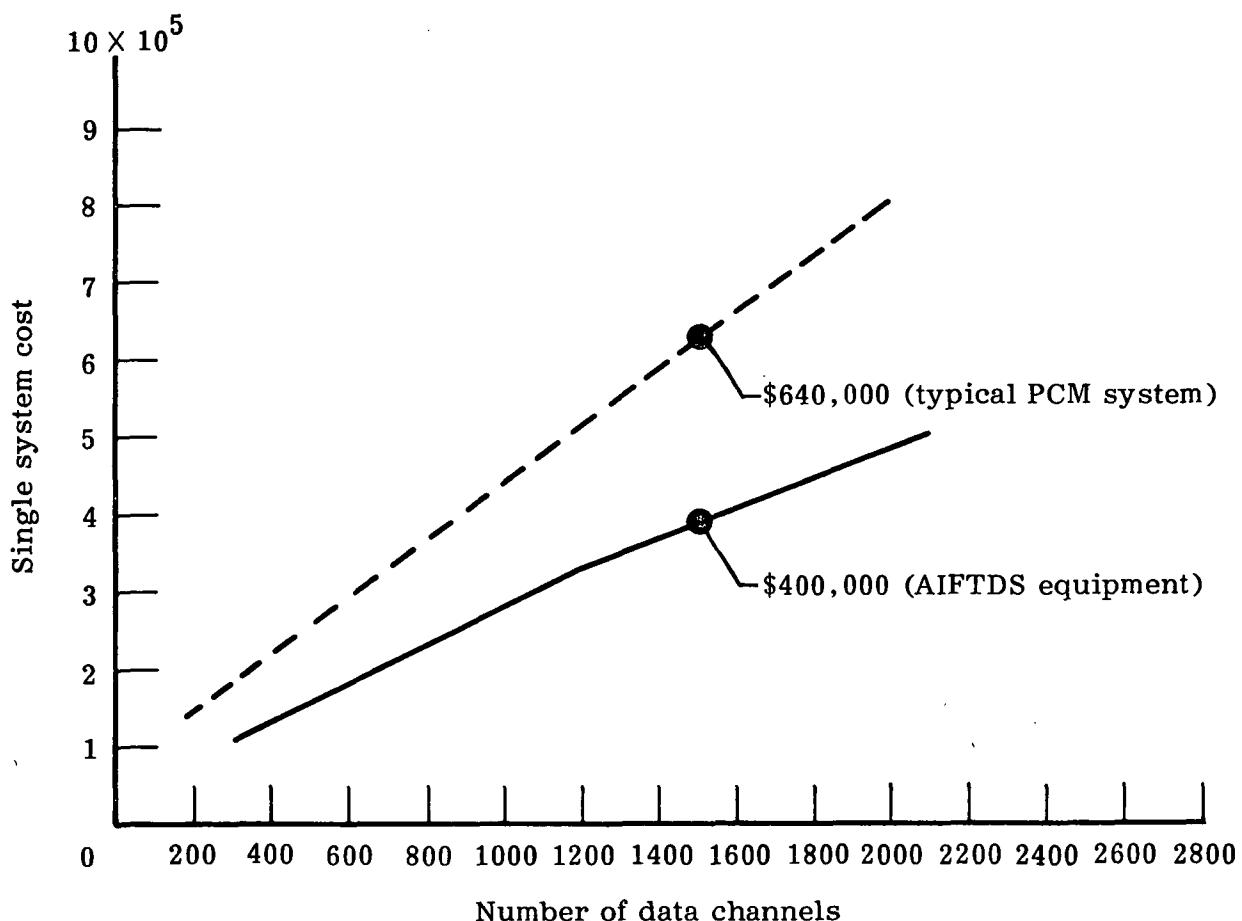
The advantages are twofold: (1) the allotted instrumentation time required for data acquisition system installation is a one-time effort, and (2) follow-on test phases can be implemented primarily by changing or altering the RMDU signal conditioning cards or the system format.

Provide Supplemental Software To Assist in Maintenance

A data acquisition system as complex as the AIFTDS must also provide appropriate testing procedures to insure proper system operation as well as definitive

System type	Approximate weight, N (lb)		Approximate volume, cu. m (cu. ft)
	System	Wiring	
AIFTDS	667.2 (150)	3336 (750)	.051 (1.8)
PCM (standard)	1200.96 (270)	13,344 (3000)	.212 (7.5)

(a) Typical weight and volume [1500-channel system].



(b) Costs (includes hardware and user non-recurring engineering through first flight).

Figure 4. Comparison of weight, volume, and costs of the AIFTDS and a typical modular PCM system.

malfunction detection. Except for test points within the ACS, proper AIFTDS operation is checked out and verified by using fixed software, in general the symbolic assembler, utility programs, the diagnostic program, and the PCM format program.

The diagnostic program has been used successfully on both the RMDU and the ACS processor. When the units were first delivered, they both had malfunctions. The diagnostic routines were applied, and the malfunctioning cards were located within a few minutes. The routine has been demonstrated repeatedly with equally satisfactory results.

Reduce Data Acquisition System Noise Susceptibility

Reduction in the susceptibility of the AIFTDS to external noise has been a by-product of the basic system design. Presumably, if the number of chassis comprising the data acquisition system is reduced to a minimum, the sensor leads shortened to a minimum, and the remote data management unit provided with a digitized output, the susceptibility of a data acquisition system to noise should be reduced. This is the philosophy used with the AIFTDS. Each RMDU is small enough in volume and is so designed that it can be installed with its own instrumentation ground system in remote areas throughout the aircraft near sensor groupings. This permits the length of the sensor wiring to be reduced to a minimum, and the RMDU data output is a high-level digital wave train.

Confirmation of improved noise reduction will require many hours of actual flight time. It should be noted that all the AIFTDS chassis have been designed to meet the military specifications for RFI, EMI, and conducted noises.

Provide Flexibility for Large and Small Aircraft

Flight-test aircraft at the NASA Flight Research Center vary in size from the XB-70 (57.6 m (189 ft) long) to the unmanned remote piloted research vehicle (RPRV) (7.9 m (26 ft) long). These aircraft all require a data acquisition system. The problems of weight, space, and power limitations in the large aircraft are not nearly as severe as in the RPRV's.

The AIFTDS RMDU was designed specifically with these limitations in mind. The RMDU can operate satisfactorily on either ac or dc input power. It has been designed to stand alone without the ACS. Thus an RMDU can be considered as a complete unit and needs only power if installed, for example, in an RPRV. The stand alone concept is made possible by a timing card which can be inserted into the card lineup replacing the digital data processing card. A wide range of timing rates is available. The RMDU then provides compatible outputs for both the telemetry transmitter and an onboard tape recorder if weight and space permit.

Provide Simultaneous Sampling and Adaptive Gain

The PCM system used at the NASA Flight Research Center samples each channel in numerical sequence. To sample a particular channel, all previous channels must

be sampled in turn. The finite time required to progress from channel to channel dictates that data parameters such as landing loads must be grouped in numerical order and hardwired accordingly so that minimum time elapses between channels. In fact, grouping is not always adequate. Experience has shown that peak landing gear impact loads cannot be satisfactorily time-correlated by PCM systems or any other time-multiplexed method when more than one channel is involved. The AIFTDS, however, can simultaneously address and sample several channels in the same instant of time, hold the data in memory, and then "clock" it out into the main data bit stream in spaces provided for by the format. The probability of sampling during the time of peak loading is improved by the high sampling rates available.

Overall data channel addressing is completely random, so any channel of any RMDU can be sampled in any order. This permits any sensor to be hardwired to any RMDU and yet be grouped by means of software formatting.

Many times valuable flight data have been lost because the fixed upper limits of the signal conditioning caused data saturation. This has been a problem, for example, during emergency situations on aircraft under flight-test conditions. Data channels most vital to analysis saturated causing the data to be unavailable until the sensor output levels dropped to within the established limits. Thus one of the design objectives of the AIFTDS was to provide adaptive gain capabilities. On the AIFTDS, anticipated data ranges are selected prior to flight; however, if these ranges are exceeded (either upper or lower), gain ranging occurs and the channel does not saturate until the sensor does.

Provide Data Management Flexibility

In general, research programs are assigned priorities. The higher priority programs are flown first and can take months, even years, to complete, particularly if only one prototype aircraft is built. During these flights, problems may occur which are not monitored because of established priority levels or insufficient data handling capabilities, or both, of the onboard data acquisition system. The AIFTDS was designed to provide enough data channels at a fast enough bit rate to allow a greater number of research programs to be performed concurrently than was previously practical. The AIFTDS PCM was designed with a maximum bit rate of 1.536 megabits per second and a 4000-channel capacity.

Experience has shown that data blocks of as many as 10 to 30 channels may be used for only 90 seconds out of a total flight time of 12 minutes. The AIFTDS has a high channel capacity and a stored format to utilize these seldom used channels for a variety of parameters at different intervals and still maintain the same data bandwidth. For these reasons a programmable data card was designed for the AIFTDS. Three data channels are independently fed into a mode select switch. The select switch is computer controlled and only one of the three is addressed at one time. The switch output is then fed through a preamplifier to a programmable low-pass filter. In this manner data channels of short usable time span, such as rocket engine burn time and landing/takeoff, can be deleted during the major portions of flight. These changes can be selected manually by the pilot. The control offers a selection of five of the 11 available formats; thus all priority levels of data may be obtained during

each flight. The result is less flight hours and an improved time history of aircraft performance.

One time-consuming area is the initial calibration of pressure sensors on flight-test aircraft. During preflight tests these sensors are exercised throughout their operational ranges, and visual readings are taken and recorded manually. The AIFTDS printer/plotter was designed as a part of this system to eliminate these manual notations and to accelerate the calibration procedure. The engineering value of each plotted point is printed adjacent to the point on the curve. The printer/plotter is portable and can be used at the aircraft with relative ease. The overall result is an automatic recording of all data and a hard-copy curve which may be retained by the engineer.

Provide for Future Growth

The addition of a computer to the airborne data system will complement the flexibility of the RMDU. The computer will control the RMDU channel sampling sequence, perform limited onboard computations for pilot or crew use, implement variable word rate and word length, and provide timing codes for the RF telemetry system and onboard tape recorders. The computer in conjunction with a suitable display unit will, on a limited basis, be used to compare selected flight parameters against preprogrammed upper and lower limits and provide the results for immediate use.

A portable address generator has been designed which will permit random addressing of any four data points with switch-selectable display of one data point's binary data while also exercising the entire RMDU at its maximum operating speed. This unit will facilitate zone-by-zone checkout of aircraft sensors without using aircraft power. This concept will be particularly useful during aircraft construction or modification when sensors need to be checked at the time of installation.

A cockpit control display unit has been designed and is now being constructed that will provide the pilot with control of the data acquisition system as well as raw or computed data display and time code information. A format-select control will permit selection of variable word lengths and word rates that are available through use of the ACS computer.

OPERATIONAL EXPERIENCE

Although it is too early in the testing phase to provide complete data on the AIFTDS capabilities, the following items have been demonstrated:

- Reduction in total weight of a typical data acquisition system.
- Total integration of sensor excitation and signal conditioning within the RMDU.
- Random channel addressing.
- Auto-ranging of input signals to the RMDU.

- Maximum bit rate of 1.536 megabits with the RMDU at 76.2 m (250 ft) cable distance.
- Flexibility by means of pluggable printed circuit cards rather than black box multiplicity.
- Interchangeability of signal conditioning cards without affecting calibrations.
- Utility software for troubleshooting diagnostic routines.
- Operation of more than one type of signal conditioning card in the same socket within the RMDU.

REFERENCE

1. Trover, William F.: A High Speed Airborne Data Acquisition and Control System With an Integrated Digital Computer. Paper presented at ITC/USA/'73 (Washington, D. C.), Oct. 9-11, 1973.